Performance Verification and Validation Plan for an NaI-tipped Cone Penetrometer System

1.0 Background

The principal soil contaminant of concern for Area B at the Ashtabula site is uranium. The Ashtabula site is currently evaluating various real-time surface scan technologies that may prove useful for cost-effectively delineating surficial uranium soil contamination. One limitation of these systems, however, is that they provide no information about the existence or extent of subsurface soil contamination. GeoProbe work combined with XRF analyses in the fall of 2001 did provide data sets to support the development of contaminated soil volume estimates for Area B. These data sets were insufficient, however, to actually delineate the extent of subsurface contamination encountered within Area B. In addition, there is evidence that there may be additional areas within Area B where subsurface contamination exists overlain by clean soils. The principal drawbacks of the current baseline (GeoProbe soil core extraction combined with ex situ soil core analyses via XRF) are the costs involved, and the turn-around time in obtaining results. The Ashtabula site has a need for a technology that can assist in better determining subsurface soil contamination extent, and in establishing that specific areas do not possess subsurface soil contamination concerns.

One option is an instrumented cone penetrometer probe developed by ARA. This probe uses a dedicated NaI sensor to provide gross gamma activity measurements near the probe tip while a GeoProbe push is underway. The advantages of this system are real-time results with no requirement that a soil core be retrieved for ex situ analysis. The principal question for this system in the context of Ashtabula is whether the system has sufficient sensitivity to identify the presence of elevated uranium in subsurface soils at the required action level of 30 pCi/g total uranium. This question has several parts:

- Is the incremental gross activity that one would expect to be associated with total uranium at 30 pCi/g sufficient to be discernible from natural variations in gross activity as measured by the NaI system?
- If so, what acquisition time is required to reliably identify elevated uraniun concentrations (i.e., 30 pCi/g total uranium)?
- If not, what elevated level of total uranium could one reliably detect with reasonable count times?

The purpose of this plan is to develop the information required to answer these questions. The results should assist in determining whether the NaI-tipped cone penetrometer system has value for the Ashtabula site, and if so, what the expected operational characteristics are.

2.0 Determination of Gross Activity Background Levels and Variability

The first step is to determine background gross activity levels for the site and identify and quantify the principal sources of background variability as observed by the NaI system.

- Background measurements will be collected from four locations in four distinct, physically separated areas within the AEMP that are believed clean based on GeoProbe work from 2001.
- Each location will consist of two pushes, the first to obtain a soil core, and the second down the same hole to obtain NaI data.
- Coring depth will be to refusal. Refusal depth should be noted in field notebooks or on soil boring logs.
- The locations where cores are obtained will be visually noted on a map of the site, with actual coordinates obtained in some appropriate manner (e.g., civil survey, GPS, or tape and chain).
- The soil core will be visually classified as to soil type (e.g., USCS, evidence of oxidation in naturally reduced glacial clays/till, "obvious" hydrocarbon or other manufacturing-liquid type staining, moisture content) in one foot intervals with this information logged in a field notebook or on soil boring logs.
- Gross activity data will also be collected in one foot intervals beginning with a depth of 18 inches, with the probe advanced one foot at a time and then kept stationary for a measurement.
- The first location will have measurement times of 30 seconds per depth. The second location will have measurement times of one minute per depth. The third location will have measurement times of 2 minutes per depth. The final push will have acquisition times of five minutes per depth.
- ***All measurements should be made using 30 second intervals. For measurements with total recording times greater than 30 seconds, the 30 second increments comprising the total count must be logged as well (i.e., a five minute count will be comprised of 10 separate 30 second readings that can then be summed).***
- Gross activity results will be logged in a field notebook or on soil bore logs in a manner that allows them to be matched to soil type information.
- One composite sample should be generated from each core and submitted for on-site full suite gamma spectroscopy analysis. This sample should be obtained by a longitudinal split of the core, with the composite constructed from soils representative of the length of the core.

The analysis of the data should include the following steps:

- If the top intervals show indications of impact (i.e., systematically yielded higher levels than deeper measurements), these should not be included in subsequent analyses.
- An average counts per-30-seconds should be calculated for each location using all of the data available for that location, except for measurements that might have been discarded because of concerns about the presence of elevated uranium concentrations.
- A site wide background average counts per-30-seconds should be constructed by averaging the averages from each of the four locations.
- For the location with 5 minute readings, each interval should have ten 30 second measurements available. The average and standard deviation of data for each individual interval should be calculated. The variability observed in static

sequential readings should follow a Poisson distribution, i.e., the standard deviation (sometimes called the counting error) of the data set should be approximately the square root of the average number of gross counts observed. If this is not the case, then this is indicative of potential instrument issues that need to be investigated.

- The variability of measurements observed down the length of a bore, after accounting for counting errors, represents the natural vertical variability in background soils at a particular location. This can be calculated for each bore by selecting, at random, one 30 second measurement from each interval for a particular bore, and then determining the variance or total variability of the resulting data set. An estimate of vertical variability is:

  $\sigma_{vertical}$ = square root(total variability – counting error^2)

  where the counting error associated with a 30 second measurement was determined in the last step.
- Comparing the average counts per-30-second computed for each location provides insight into how one might expect background to vary laterally across the site. This can be calculated by selecting, at random, one 30 second measurement from each interval for every bore, pooling these results, and then determining the variance or total variability (σ^2_{total}) in the resulting data set. An estimate of lateral variability is:

  $\sigma_{lateral}$ = square root(σ^2_{total} - $\sigma^2_{vertical}$ – counting error^2)
- Using the collected background data, one can calculate the incremental gross activity counts necessary for reliably identifying a particular elevated activity concentration. This analysis should be done using the 30 second measurement time data set. Assuming that the desired probability of making a false positive error is 5%, for a particular measurement time the gross activity level incremental to background which likely denotes something above background (L_c) is:

  $$L_c = 1.645 * \mathrm{sqrt}(\sigma^2_{total})$$

  where σ^2_{total} is the total variability one observes in background gross activity measurements with a 30 second measurement time.

  Assuming that the desired probability of making a false negative error is also 5%, then the incremental gross activity that represents the detection limit (L_d) for the instrument assuming a 30 second measurement time is given by:

  $$L_d = 3.29 * \mathrm{sqrt}(\sigma^2_{total})$$

The question for the NaI system is whether gross activity background plus L_d represents a total uranium concentration that is less than 30 pCi/g (in other words, the detection limit is less than 30 pCi/g). If this turns out to be more than 30 pCi/g, the follow-up question is how low detection limits can be dropped by reasonably increasing measurement times. The answer to the latter depends on the relative contributions of counting error, vertical variability and lateral variability to the total variability observed in background 30 second readings. One would expect that vertical variability would dominate the sources of error for 30 second gross activity measurements at background levels.

3.0 Detection Limit Analysis, System Calibration, and Determination of Gross Activity Triggers T_1 and T_2

The next step is to collect information that can be used to complete the detection limit analysis, develop calibration equations for the system, and determine incremental gross activity triggers T_1 and T_2 that will be used when the system is delineating uranium contamination extent. The results from this work will determine whether the NaI has sufficient sensitivity to detect total uranium at 30 pCi/g reliably with a 30 second acquisition time (i.e., do samples with gross activity in the range of background+ L_d yield total uranium results less than 30 pCi/g?). The results should also provide the basis for estimating what the likely average incremental response (T_{30}) of the NaI would be to 30 pCi/g total uranium for a 30 second acquisition.

- Select areas where uranium concentrations are expected to be above 30 pCi/g for total uranium over a significant depth range (e.g., more than four feet). The two likely areas for this work are adjacent to the RF3 Butler Building/Burn Pad and immediately north of the Main Plant building. In both cases the 2001 GeoProbe work encountered uranium contamination to depths of at least four feet.
- A minimum of four cores should be collected, with attention focused on locations that can be expected to yield contamination at depth (e.g., four feet or more). Coring should continue to a depth of 12 feet. Additional cores may be required if the depth of contamination encountered is not sufficient to generate 20 physical soil samples that meet the needs of the performance evaluation work.
- The soil cores should be visually characterized as with the background bores, with this information logged in a field notebook or on soil bore logs.
- The resulting holes should be profiled with the NaI sensor using 30 second measurement times at one foot intervals beginning with a depth of 18 inches.
- For any particular hole, if none of the NaI readings yield a result greater than background+L_d, the hole should be abandoned and a replacement location selected.
- For holes that are retained, at least one depth in each hole should have 10 sequential 30 second static readings. The depth selected should be the depth that has yielded a gross count closest to background plus the L_d already calculated.
- At most five samples should be selected from each of the cores and submitted to the on-site laboratory for gamma spectrometry analysis. Samples should be representative of a one foot interval centered on the depth of corresponding NaI readings, with soils completely homogenized. One sample should correspond to the depth where the sequential measurements were taken. The second sample should correspond to the interval with the highest NaI reading. The third sample should be taken from the first soil interval that is below background+L_c. The other two samples should be taken from intervals with gross activity readings that are in the range of background+L_c to background+L_d, if such intervals exist. If there are no samples in this range, then forego sampling. If, after four cores,

twenty samples have not been obtained, then select additional core locations and continue data collection until a total of twenty samples have been obtained.

The analysis of the data should include the following steps:

- Review the static sequential 30 second readings from the holes. Calculate the standard deviation associated with each set of static readings. Compare this value to the square root of the average 30-second reading for each location. If it is significantly greater, this would suggest potential instrumentation problems. Also, plot the data for each location as a function of time to see if any "drift" is visually evident. The presence of drift would also be indicative of potential instrumentation problems.
- Perform a linear regression on the resulting NaI/total uranium data sets, regressing total uranium activity concentrations as measured in the laboratory against gross activity as measured by the NaI. Use the resulting regression to estimate the incremental gross activity (T_{30}) that would be associated with 30 pCi/g total uranium with 30 second acquisition times. In doing this regression, no more than one data pair (i.e., combination of gross activity and gamma spec result) should be used per interval measured. For intervals where there are multiple pairs (e.g., locations where sequential NaI readings were collected), the average of the 30-second-readings should be used.

  If T_{30} is less than L_c, then the NaI instrument is providing little information regarding the presence or absence of total uranium contamination above 30 pCi/g with a 30 second measurement time. Additional data analysis should be done to determine if increasing measurement times is likely to reduce detection limits to something below 30 pCi/g. The regression analysis should also be used to determine the uranium activity concentration that background plus L_c represents. This would represent the uranium activity concentration that the GeoProbe would be able to identify at least 50% of the time. The GeoProbe NaI can be used to assist in identifying areas that exceed this identifiable concentration, but will not be useful for "clearing" areas of uranium contamination at 30 pCi/g. In this case there will need to be heavy reliance on alternative techniques (e.g., gamma spectroscopy or XRF of core samples). T_1 and T_2 have no meaning in this context.

  If T_{30} is above L_c but below L_d, then the NaI can detect 30 pCi/g, but not reliably with a 30 second measurement time. T_1 should be set to L_c and used as the incremental gross activity trigger level for identifying intervals that pose possible uranium concerns. Additional data analysis should then be done to determine the false negative rate that using this T_1 would produce. This will be important from the perspective of confidently using NaI data to "clear" areas of concern for subsurface uranium contamination. In this case, there will need to be some soil sampling from cores to "clear" areas of concerns as work proceeds forward. T_2 should be set to T_{30}, and used as the incremental gross activity trigger level for identifying intervals that are likely to pose uranium concerns.

If T_{30} is above L_d, then the NaI can detect 30 pCi/g reliably (i.e., the detection limit for the instrument is less than 30 pCi/g) with a 30 second count time. T_1 can be estimated as follows:

$$T_1 = T_{30} - 1.645 * \text{square root}(\sigma^2_{total})$$

where T_{30} is the gross activity associated with total uranium at 30 pCi/g for a 30 second measurement. T_2 in this case should be set to T_{30}.

If a 30 second acquisition time does not prove to be sufficient to obtain the desired detection limits, additional data analysis can be done to determine if there is a reasonable count time that does provide the desired results. It is important to note, however, that a 30 second acquisition time is likely to provide counting errors that are smaller than the natural variability one would likely see in background gross activity, and consequently lengthening measurement times may have minimal impacts on lowering detection limits.

For the sake of implementation efficiency, one would like to use the shortest measurement time that provides T_{30} greater than L_d. It may be the case that there is no "reasonable" measurement time that achieves this goal. In this case, T_1 would be selected based on the longest "reasonable" measurement time available, recognizing that the NaI would not have sufficiently low detection limits to reliably identify 30 pCi/g total uranium. It is also important to note that measurement times need not be constant during actual data collection. If heavy contamination is encountered, this will be readily identified with a short measurement time and there would be no need for longer counting. In any case, as gross activity measurements are made and recorded, it will be important that measurement times as well as gross activity nuhmbers are logged.